SUPERSPEED COMPUTERS: A MAJOR TOOL IN THE SPACE SCIENCES

by

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In 1965 we stand on the threshold of a new are in the research uses of computers.

Steady improvements in calculating speed and memory capacity of the computer have finally produced a subtle, qualitative change in its character. We have the prospect before us, in the machines coming on the market in 1966 and 1967, of using the computer not as an abacus, but as a laboratory for the performance of experiments. This transformation in the character of the computer is particularly important in the space sciences.

How can a computer be equated with a laboratory? The understanding of this peculiar statement requires some knowledge of the way in which the physicist looks at the natural world.

According to the research of the last 50 years, all matter is composed of a few fundamental building blocks -- the neutron, proton, and electron. These particles are cemented together in combinations of various sizes to form the hierarchy of structure in the natural world, ranging from the atomic nucleus to such massive bodies as planets, stars and galaxies. The organization of units of matter, and their interactions with one another, are controlled by four basic forces of nature -- a strong and a weak nuclear force, the force of electromagnetism, and the force of gravity. Most powerful of all is the strong nuclear force, which cements neutrons and protons together into the tightly bound nucleus of the atom. Next is the electromagnetic force, which is approximately 100 times weaker than the nuclear force. Least powerful is the force of gravitation; this frail agent keeps the moon in orbit around the earth, the earth and the other planets revolving around the sun, and the sun and other stars clustered together in our Galaxy.

All experiments in the natural sciences are designed either to study the fundamental building blocks of matter and the basic forces which control their interactions; or, using existing knowledge of the basic forces and particles, they are designed to investigate large numbers of these particles, whose collective behavior is too complex to be readily understood in terms of the individual units.

With these circumstances in mind, let us re-enter the laboratory. In a laboratory experiment a sample of matter is manipulated to observe its response to artificial disturbances under carefully controlled conditions. If the physicist is motivated by a desire to learn more about the fundamental building blocks of matter, and the forces which act between them, he will choose for this experiment a very simple collection of particles whose individual responses can be observed. During the last 30 years, nuclear forces have been studied in this way by experiments performed with high-energy accelerators.

On the other hand, the experimenter may have an adequate knowledge of the basic forces and particles, but be seeking more information about the behavior of the whole ensemble of atoms as a unit. The biochemist, for instance, seeks to unravel the tangled sequence of chemical reactions between large groups of atoms, which make up the business of life.

These procedures have worked exceedingly well in both types of situations. Science has achieved its greatest successes through the development of such techniques for experimentation under controlled conditions in the laboratoty.

But in the space science program, opportunities for this kind of laboratory experimentation are generally not available. The object under study in space science, which may be an entire star, a planet, or the atmosphere of a planet, is too large to be brought into the laboratory or to be manipulated artificially in its native state.

Consider, for example, the weather. In order to arrive at an understanding of the causes of weather, we must experiment with the atmosphere by adding heat to one part of it under controlled conditions, and observing its response. But when it is observed that one ordinary hurricane releases the energy of 10,000 hydrogen bombs, we see that it is not feasible to carry out such experiments on the weather.

The new computers coming on the market have, for the first time, a sufficient memory capacity so that we can store in one of these machines a relatively complete description of the atmosphere, including atmospheric temperature and pressure and ground conditions all over the globe. We can also store the basic laws of physics which determine the response of the atmosphere to the energy received from the sun.

The computer can apply the basic laws to each part of the atmosphere, calculating the new conditions which will result from the extension of the existing atmospheric motions over a small interval of time. Then, with the new conditions as the starting point, the computer program again applies the basic laws to obtain the atmospheric conditions after a second small interval of time.

A million repetitions of this process may be necessary to follow the development of weather over a long period of time. The number of additions and substractions can amount to 10 trillion simple steps for one such study. Only the computers now arriving on the market contain <u>both</u> the memory capacity required to store an adequately complete description of the atmosphere, <u>and</u> the speed necessary to complete this vast amount of arithmetic in a reasonable time.

With the new computers we will move much closer to our ultimate objective -- which is to vary the regional input of solar energy and the conditions on the ground, by feeding different numbers into the computer, and, thereby, to determine, by machine calculations, the effect of these variations on global weather.

In such calculations, the computer is used as a means of carrying out an otherwise impossible experiment on the behavior of the atmosphere. The experiment is numerical, and does not involve actual molecules of air. Yet those molecules of air are in the computer, nonetheless, because the computer contains a complete electronic record of these properties stored in its memory.

Now let us transform this machine from an imitation of the earth's atmosphere to an imitation of some other body which we wish to study. There is a great deal of interest, for example, in the conditions which exist within the body of a star such as the sun. We may wish to study the history of the sun from the time of its formation, 4.5 billion years ago, to the present. Such a study yields information about the physical conditions which existed in the early years of the solar system, when the planets were formed.

An abundance of observational evidence indicates that the sun and other stars are born in a natural condensation of the gas and dust which fill space. It is thought that planets are formed in a similar manner, as smaller condensations in the cloud of partly compressed gas which surrounds the star at the time of its birth. Astrophysical evidence indicates that the formation of planets in this way is a frequent accompaniment to the birth of stars, and that planets are a commonplace feature of the universe.

In our own solar system, it is believed that life developed on the earth about three and a half or four billion years ago, one billion years after the formation of the sun and the planets.

It is not clear how the transition occurred from a soup of inanimate matter made up of complex organic molecules, to the mysterious substance of life. It is possible that an understanding of this mystery may forever be denied us. Nonetheless, molecular biologists are making amazing progress toward a mechanistic description of the living cell in terms of chemical reactions. Scientists who are acquainted with the most recent advances in molecular biology and who have followed the developments relating to the evolution of the stars and planets, have a growing impression that a credible description of the origin of life on the earth may come out of the union of these two streams of inquiry.

It is important to realize that the early properties of the sun, and the physical conditions which existed on the earth in its first billion years, were almost certainly quite different from those that exist today. These differences play a critical role in our attempts to understand the development of physical life on this planet. Unfortunately, it is not possible to learn anything about the evolution of the sun and the planets by direct observation in the scale of human lifetimes. Hundreds of millions or billions of years must elapse before appreciable changes occur in the properties of a planet or a star. It is also not possible to apply outside forces to the sun or a planet and observe its response, in an analogue to a controlled experiment in the laboratory, because the energies required are, once again, beyond human manipulation.

We can, however, perform this laboratory experiment with a computer, provided we have a good enough knowledge of the basic laws which govern the properties of stars and planets. For this purpose we can use the same computer which previously imitated the earth's atmosphere. We can transform a high-speed computer from an imitation of the earth's atmosphere to an imitation of the sun or the planet earth, by erasing the description of air molecules which is recorded within the machine, and feeding into the computer a new set of punched cards which contains a description of the atoms of the star or a planet instead. In this way we make the computer change its character from a planetary atmosphere to a flaming body of gas, or a cold body of rock. When these changes have been made, the machine is now ready for service as a device which will yield information on the life history of the sun or the earth.

Knowing the laws of nuclear physics which generate the energy by which the sun burns, and inserting these laws into the machine, we learn how the sun must have behaved. Knowing the properties of the materials which make up the earth's interior, we discover how the earth must have evolved since it first condensed out of the primitive solar nebula. In this way, with the aid of computers, we look backward into the history of the solar system to a time which preceded the existence of living organisms, and learn something about the physical conditions on the primitive earth which may have led to the appearance of man on the face of this planet.